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Research Paper

Geospatial Assessment of Flood Vulnerability of Developed Properties in Calabar Metropolis, Cross River State, Nigeria

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Abstract
An important aftermath of flooding is the damage to physical structures such as buildings, bridges, roads, and public utilities. Through Remote Sensing and Geographic Information System techniques, the level of vulnerability of an entity can be established. The study assessed the flood vulnerability level of developed properties in Calabar Metropolis using geospatial techniques. Physical environmental domains such as land use, elevation, and proximity to river channel (drainage) were used to establish the developed properties vulnerability level. Finding revealed that waterbody and built up area were found to be highly vulnerable to flood based on landuse use types and they account for 43.73% of the total area of Calabar. The analysis revealed that 121 developed properties were under the low flood vulnerability level and this amounted to 27.50% of the total number of developed properties captured. Similarly, 208 (47.27%) developed properties were found under the moderately flood vulnerability while 111 (25.23%) of developed properties were found under the highly flood vulnerability level. The study concluded that most of the developed properties in the metropolis have medium level of vulnerability. The study recommended the need for various engineering reinforcement to improved developed properties resilience to flood action.
Keywords*: Geospatial Analysis, Developed Properties, Flood Vulnerability, Physical Vulnerability*

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I. Introduction

The vulnerability of the built environment to floods is referred to as physical vulnerability. An important consequence of flooding is the damage to physical structures such as buildings, bridges, roads, and public utilities. According to the World Bank (2014), 'physical vulnerability encompasses the structural and non-structural damage to buildings or building components or other infrastructure'. These damages could be direct, in terms of gradual and consistent deterioration of buildings and other infrastructure (WB, 2014; Fatemi, *et al*., 2020).Flood damage on buildings are often extensive and deteriorates their material compositions and structures as well as their function (Blanco and Schanze, 2012).The IPCC thus indicates that vulnerability encompasses a variety of concepts including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. Therefore, information on the elements at risk (e.g., people; built environment; eco-systems), the exposure (e.g. proximity to the river; elevation of the area; frequency, duration, and depth of floods),and areas' susceptibility(e.g. socio-economic capacities, coping, and recovery) are essential for assessing physical damage due to flood (Yankson, *et al*., 2017; Ugwu 2017; Fatemi, *et al*., 2020).

Cities have varying degrees of risk exposure based on their location relative to hazard source and their socio-economic circumstances (Samuel, *et al*., 2017). The inhabitants of these cities are likely to differ in their perception, not only of risk, but also of the resultant disaster events and possibly their impacts including damage to properties. More recently, vulnerability assessments have explored the social, economic, and political conditions that are likely to affect the capacity of individuals or communities to cope with or adapt to hazards (Cutter, 1999; Karmakar *et al.*, 2013). In Nigeria, several studies have been carried out on vulnerability assessment using various techniques including Remote Sensing and GIS techniques (Happy, *et al*., 2014; Eguaroje, *et al.*, 2015, Gelleh *et al*., 2016; Nkwunonwo 2017; Samuel *et al*., 2017 and Chigbu et al., 2018;

Afolabi et al., 2022) to ascertain the vulnerability level; however, none of the studies considered vulnerability from developed properties perspective. Therefore, the study assessed flood vulnerability level of developed properties in Calabar Metropolis using geospatial techniques.

II. Materials and Methods

Study Area

The study was conducted in Calabar Municipality (Figure 1). The area is located between Latitudes 04˚50´ and 50˚ 10´ North of the Equator and Longitudes 08˚ 18´ and 08˚ 37´ East of the Greenwich Meridian and on an altitude of 27 m to 36 m above sea level (Okon et al., 2019). The area is characterized by two distinct tropical moist climates – the rainy and dry seasons. The dry season occurs from November to February, while rainy season occurs between March and October. The agroclimate of the area is typical of the humid tropical region marked by excess rainfall over evapotranspiration for about eight months in a year. Geologically, the area has parent material consisting of Coastal Plain Sands (Bulk-trade, 1989). The area is well drained, very porous with soil depth extending up to two meters deep and gentle sloping with a predominance of sheet and rill erosion. The soils of the area had been classified as Typic Paleudults in the Ultisols order using USDA soil taxonomy (Esu, 2005).

Sources of Data

This study employed the use of both primary and secondary data.

The primary data included:

i. Landuse map of Calabar Metropolis acquired from the Landsat imagery of 30m x 30m

ii. Drainage Network, Road Network, Communities location, and Soil map extracted from the topographic map of 1: 100,000 of the study area.

iii. Resilience Capacity Assessment Instrument (questionnaire)

The secondary data included:

iv. Topographic guide of the investigation zone from Surveyor General's Office, Ministry of Lands and Survey, Cross-River State

v. Landsat symbolism of 30 m x 30m of 2015 got from the US Geological Survey.

Geo-Information and Vulnerability Map Generation

The imagery of Calabar Metropolis and the topographical map were geo-referenced to the world coordinate system (WGS 84) in ArcGIS 9.3. From the imagery, the land use map of the study area was acquired, while the drainage network, road network, and communities were imitative from the topographical map. In addition, the soil texture map of Calabar Metropolis was also geo-referenced to WGS 84.

Vulnerability Criteria: This study used ranking methods of the vulnerability factors embedded in the Analytical Hierarchy Process (AHP) proposed by Saaty (1980). AHP is a multi-criteria basic leadership method, which gives a methodical way to evaluate and incorporate the effects of different variables, including a few dimensions of reliant or autonomous, subjective just as quantitative data (Bapalu and Sinha, 2006; Berezi, 2019). The ranking method was adopted because the criterion weights are usually determined in the consultation process with choice or decision-makers, which resulted in a ratio value assigned to every criterion map (Lawal *et al*., 2011). In positioning strategy, each measure under thought is positioned at the request of the leader's inclination. To create rule esteems for every assessment unit, the evaluated essentialness weighted each factor for causing the flood.

i. *Landuse Map of Calabar Metropolis**:*** The geo-referenced Landsat imagery was exported to Idrisi Selva for the generation of the land use map of Calabar Metropolis. A supervised classification technique was adopted using the MAXLIKE (Maximum Likelihood Algorithm) module to generate the land use/land cover types in the area. The area is a square kilometre of each land use type that was calculated. The land-use type was converted to vector using Feature to Polygon in the ArcGIS environment. The land use identified were thick vegetation, sparse vegetation, developing area, built-up area, and water body.

ii. *Proximity to river channels (Drainage):* The drainage network which determines the proximity to river channels and communities was mapped from the topographical map. These geographic features were digitized and captured as vector data in ArcGIS 10.6.

iii. *Elevation Map of Calabar Metropolis:* The elevation map was derived from the height above the mean sea level directly from the Google Earth image. A 10 x 10 grid system covering Calabar Metropolis was created in ArcGIS 9.3 and imported into the Google Earth interface. The latitude, longitude, and height in meters at the centre of each grid were recorded and input in Microsoft Excel 2007 Version. The latitude, longitude, and height of each point were then imported to ArcGIS 9.3 and were used to generate the elevation map through the interpolation method.

The land use, proximity to river channels (drainage), and elevation maps were reclassified into high vulnerability, moderate vulnerability, low vulnerability, and no vulnerability.

i. *Reclassification based on Landuse types:* Four (4) types of terrain were observed concerning their distance to the rivers. In terms of the land use map, the thick vegetation was reclassified to low vulnerability, farmland/sparse vegetation to moderate vulnerability, while built-up areas and water bodies as high vulnerability.

ii. *Reclassification based on drainage network:* In terms of the drainage network, the communities were rated based on their proximity to rivers in the study area. Buffering method was used whereby zones of influence were generated as rings of 500 meters, 1000 meters, and 1500 meters from the rivers. The ring of 500m was regarded as high vulnerability, 1000m as moderate vulnerability, and 1500m as low vulnerability (Mmom and Ayakpo, 2014).

iii. *Reclassification based on elevation:* The elevation map was also reclassified as follows 1.6m-4.6m to high vulnerability, 4.7m-7.6m to moderate vulnerability, and above 7.7m to low vulnerability.

The vulnerability levels were assigned values 3, 2, and 1 to high vulnerability, moderate vulnerability, and low vulnerability, respectively, by applying the ranking method to the factors. Using these values, the land use vulnerability map, drainage network vulnerability map, soil texture vulnerability, and elevation vulnerability map were overlaid in ArcGIS 9.3 with the use of the UNION MODULE. The reclassification method was also applied to have the very high vulnerability, high vulnerability, moderate vulnerability, low vulnerability, and very low vulnerability. The output of this map was regarded as the flood vulnerability map of Calabar Metropolis, considering the land use, proximity to river channels (drainage network), elevation, and soil texture maps of the area. Finally, a spatial query in ArcGIS 9.3 was used to determine the vulnerability levels each community fell into and the spatial extent of each vulnerability level.

III. Result and Discussion

Landuse Pattern of Calabar Metropolis: The Landuse pattern analysis is captured in Figure 1-2 and Table 1. The analysis reveals that waterbody covered a spatial extent of 23.11 sq km (6.73%), riparian vegetation/freshwater swamp covered 57.53 sq km (16.75 %), thick vegetation had 95.97 sq km (27.94 %), built up area covered 127.10 % (37%) and farmlands covered 39.78 sq km (11.58 %). The group of waterbody and built up area which are found to be highly vulnerable to flood based on landuse use types covered altogether 43.73% of the total area of Calabar. Low vulnerable area covered 27.94% while the moderate vulnerable area based on landuse only covered 18.31% of the total area of the study location. The study conducted by Afolabi et al. (2022) and Berezi et al. (2019) established the influence of landuse in flood vulnerability studies. The built-up area was regarded as a high vulnerability because the presence of hard surfaces can prevent easy infiltration and thereby enhance higher runoff which can easily cause flood (Berezi et al., 2019; Afolabi et al. 2022).

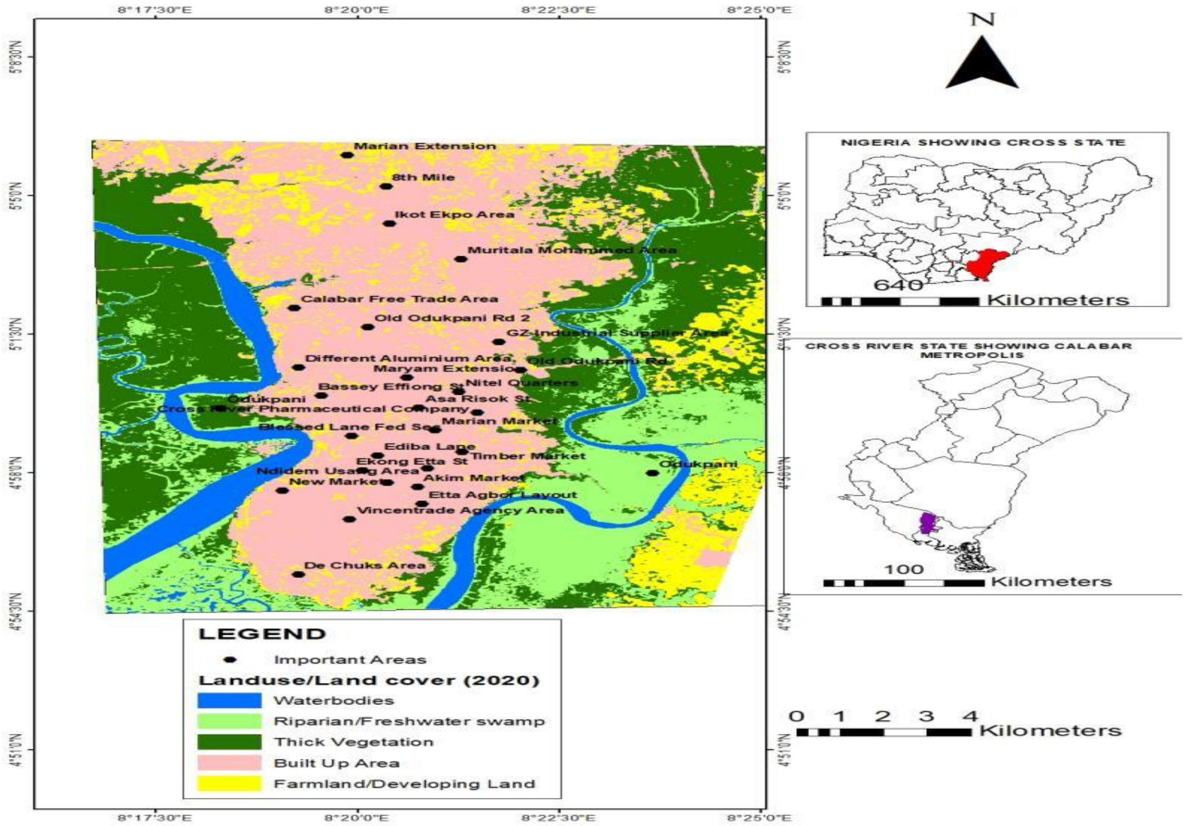

Figure 1: Landuse Pattern in Calabar in 2020

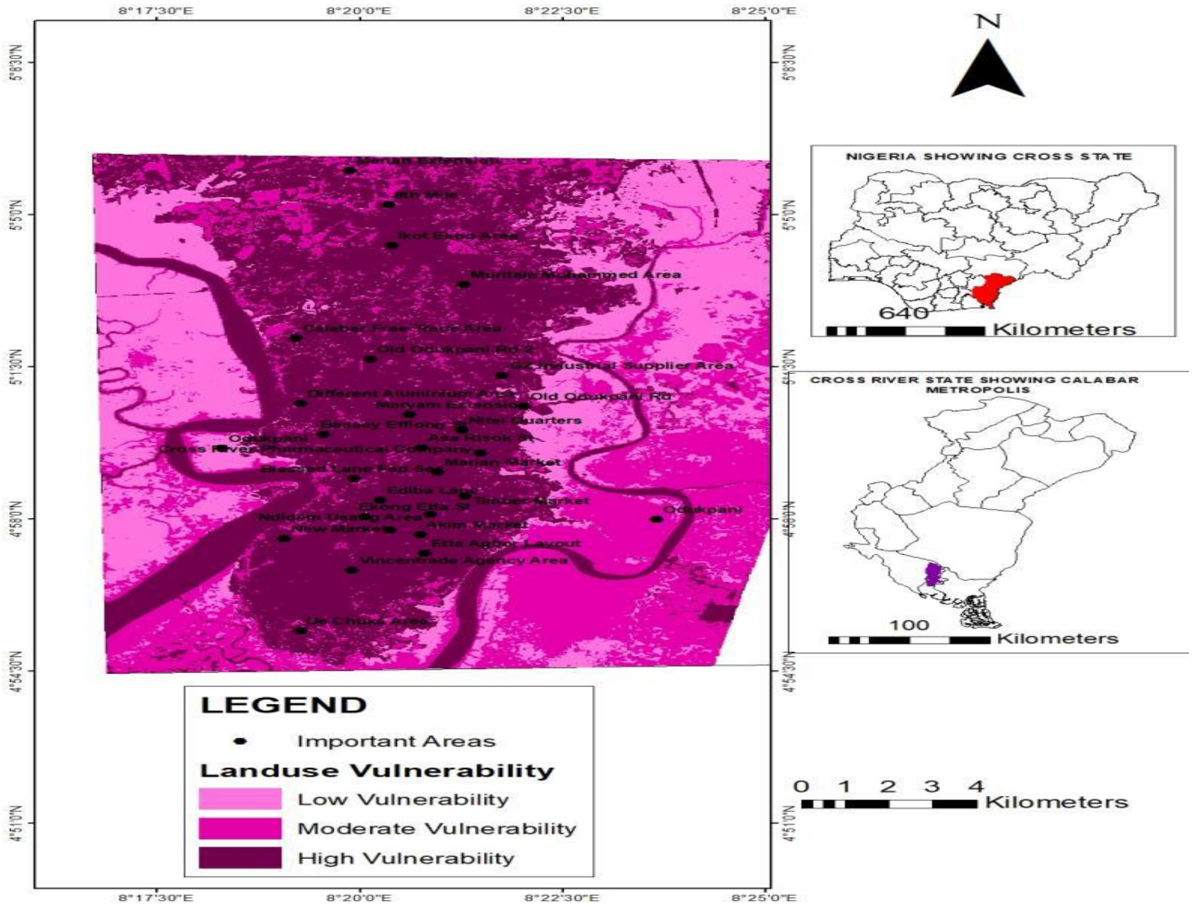

Figure 2: Landuse Vulnerability to Flood in Calabar

Table 1: Landuse/Landcover Vulnerability Levelsto Flood in Calabar

S/n	Landuse	Spatial Extent (Km^2)	Percentage (%)	Vulnerability Assigned Values	Vulnerability Levels
1	Waterbody	23.11	6.73	3	High Vulnerability
2	Riparian/Freshwater Swamp	57.53	16.75	2	Moderate Vulnerability
3	Thick Vegetation	95.97	27.94	1	Low Vulnerability
4	Built Up Area	127.10	37.00	3	High Vulnerability
5	Farmland/Developing	39.78	11.58	2	Moderate Vulnerability
	Total	343.49	100.00		

*Proximity to River Channel (Drainage)***:** The analysis concerning the proximity to active channel as a determinant of the flood vulnerability levels is displayed in Figure 3-5 showing the active river channels, the buffering analysis from the active river channels and level of vulnerability based on active river channel only. The analysis thus revealed that at 500m from the active river channel, which is classified to be highly vulnerable occupied 62.64 sq km (39.03%), while the distance of 1000 m occupied 54.84 sq km (34.17%) while a distance of 1500 m occupied 43.03 sq km (26.81 %) (Table 2). The area covered by the high vulnerability to flood in Calabar was the highest while the least was the low vulnerability.

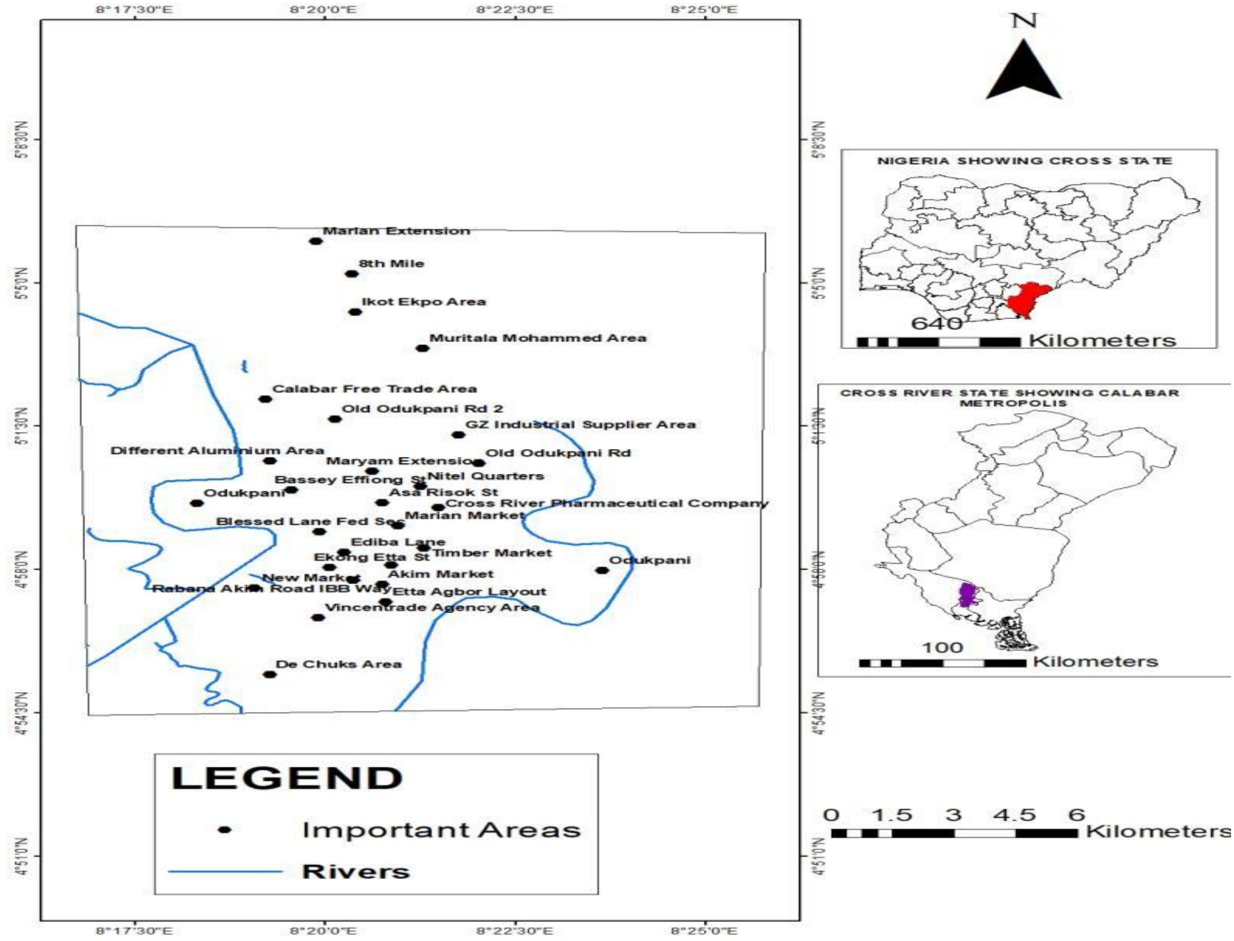

Figure 3: River Channels in Calabar

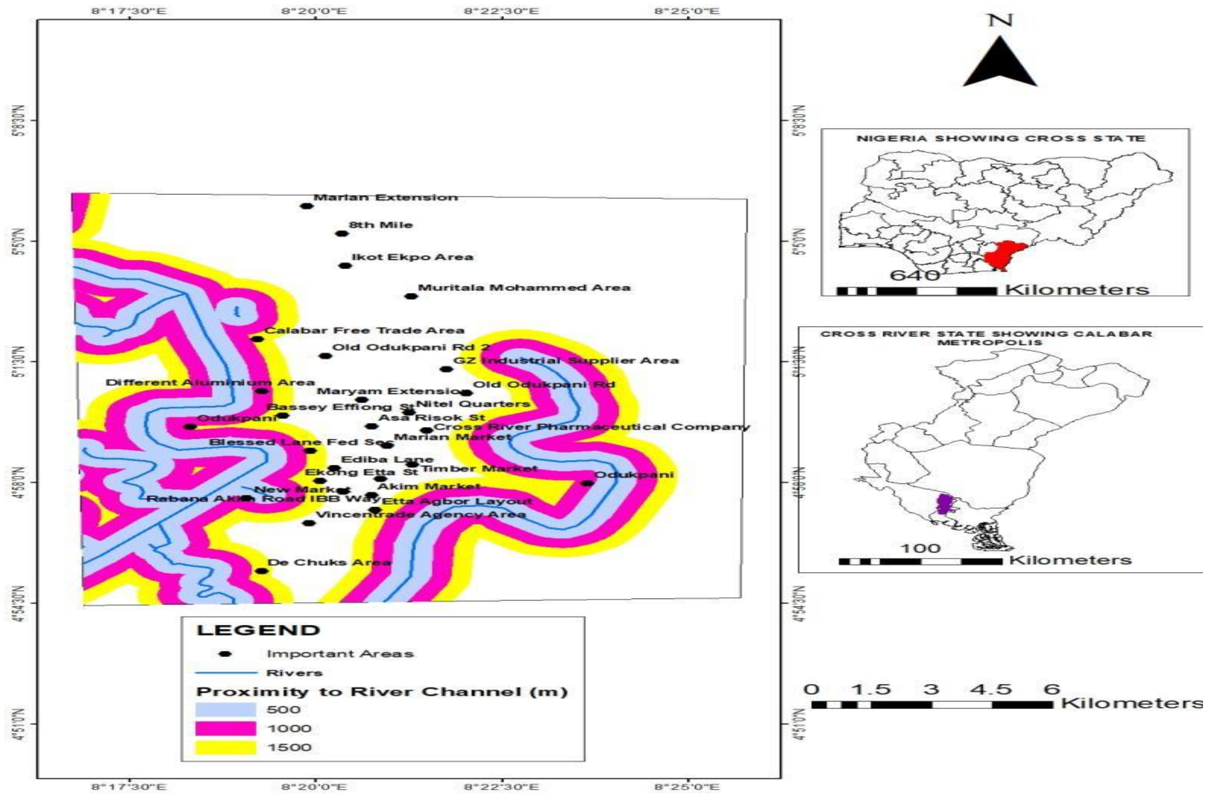

Figure 4: Proximity to River Channel Analysis in Calabar

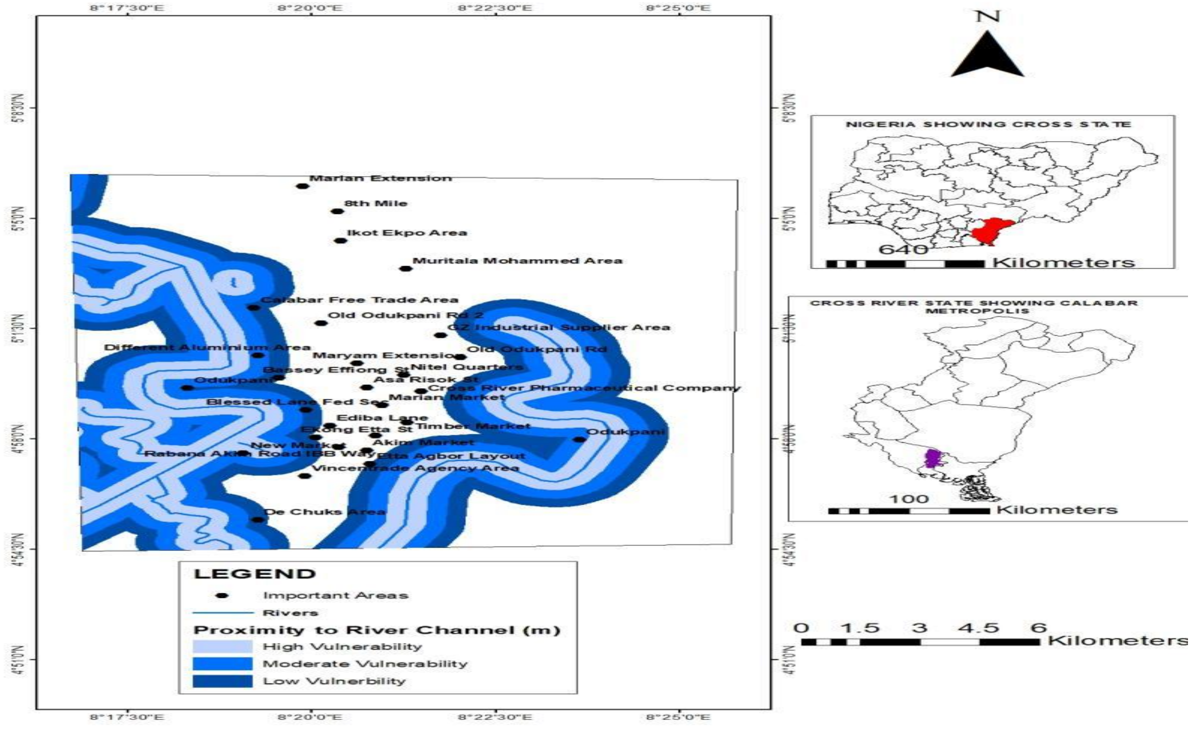

Figure 5: Proximity to Active River Channel Vulnerability Level in Calabar

Table 2: Proximity to Active River Channel

S/n	Drainage Buffer (m)	Spatial Extent (km^2)	Percentage (%)	Vulnerability Assigned Values	Vulnerability Levels
1	500	62.64	39.03	3	High Vulnerability
2	1000	54.84	34.17	2	Moderate Vulnerability
3	1500	43.03	26.81	1	Low Vulnerability
	Total	160.51	100.00		

Soil Texture Vulnerability: The soil texture of Calabar as displayed in Figure 6-7 and Table 3 are Coarse texture, medium texture and medium/fine texture. The analysis showed that the coarse texture occupied 93.19 sq km (26.01%), medium texture occupied 0.41 sq km (0.11%) while medium/fine texture occupied 264.67 sq km (73.87%). Based on their level of vulnerability to flood, high vulnerability occupied 73.98% while moderate vulnerability occupied 26.01%.

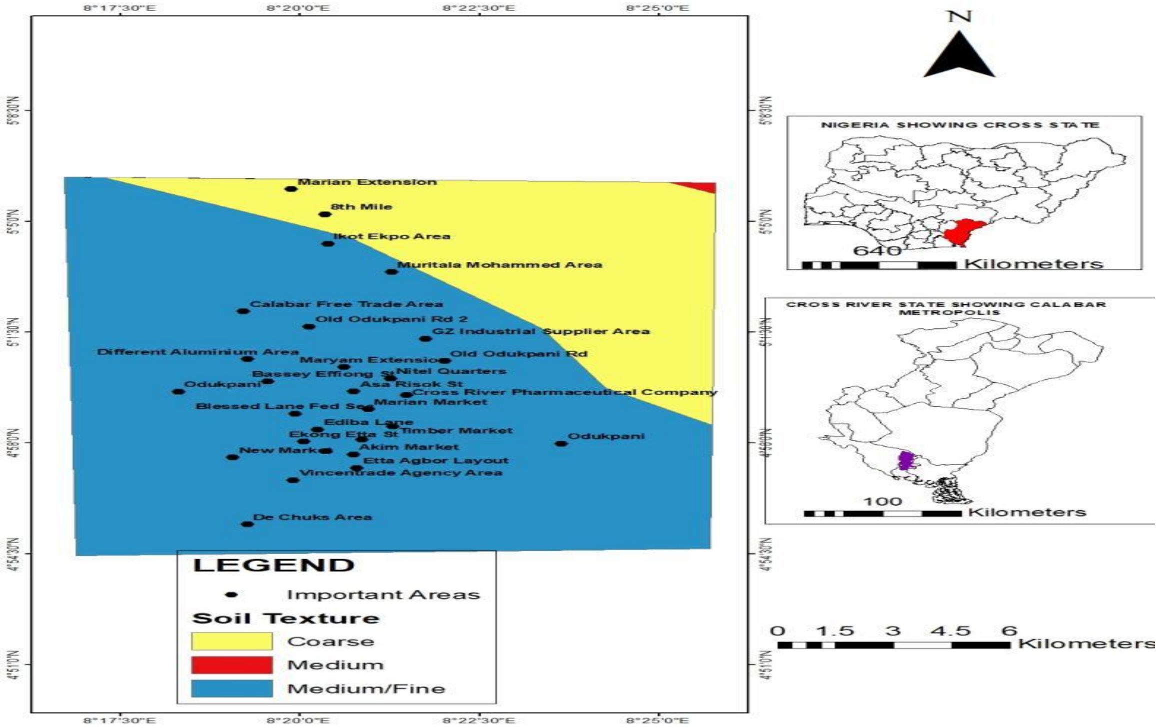

Figure 6: Soil Texture of Calabar Township

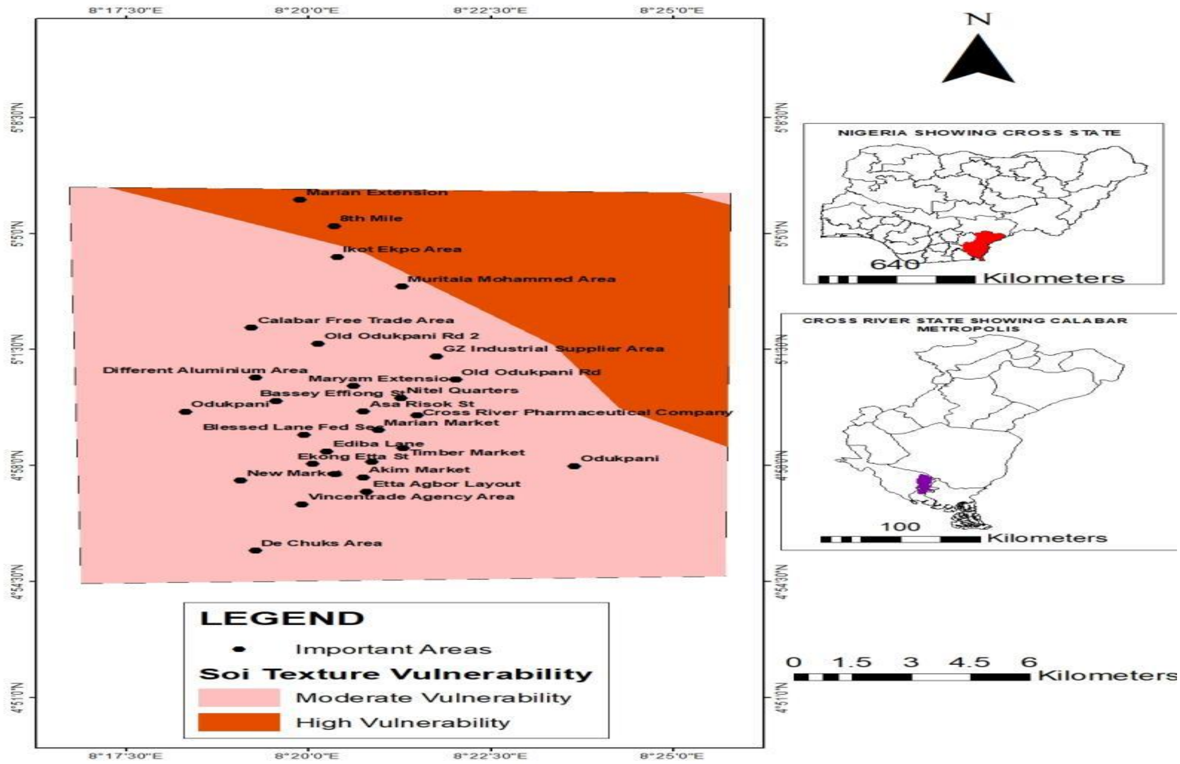

Figure 7: Soil Texture Vulnerability to Flood in Calabar

Table 3: Soil Texture Vulnerability of Calabar Town

S/n	Soil texture	Spatial Extent (Km^2)	Percentage (%)	Vulnerability Assigned Values	Vulnerability Levels
1	Coarse Texture	93.19	26.01	2	Moderate Vulnerability
2	Medium Texture	0.41	0.11	3	High Vulnerability
3	Medium/Fine Texture	264.67	73.87	3	High Vulnerability
	Total	358.27	100.00		

Elevation: The elevation level, classified elevation levels and elevation vulnerability to flooding are displayed in Figure 8, Figure 9 and Figure 10 respectively. Table 4 also presents the analysis of elevation levels in values whereby it is found that the elevation ranging from 0m to 13 m was classified the high vulnerability area which covered the spatial extent of 91.13 sq km (25.44%). From 14m to 53m, this was classified to be moderate vulnerability which occupied 215.72 sq km (60.19%) while from 54m to 96m, the spatial area extent occupied was 51.49 sq km (14.38%). The flood vulnerability of the states in the Niger Delta region has been connected to elevation characteristics by several studies (Happy et al., 2014; Amangbara & Obenade, 2015), which is reflected on the elevation analysis of Calabar metropolis.

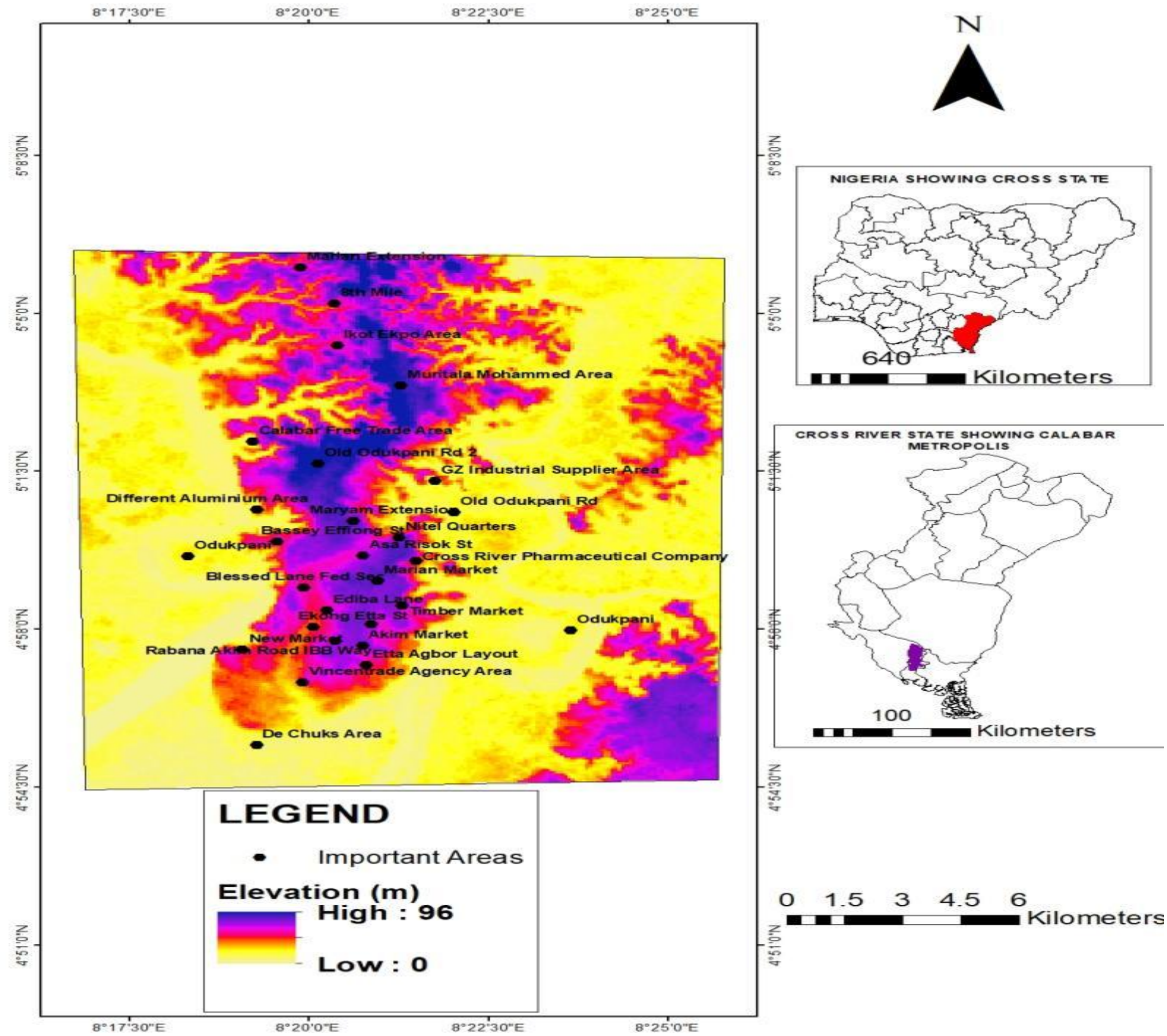

Figure 8: Elevation model of Calabar

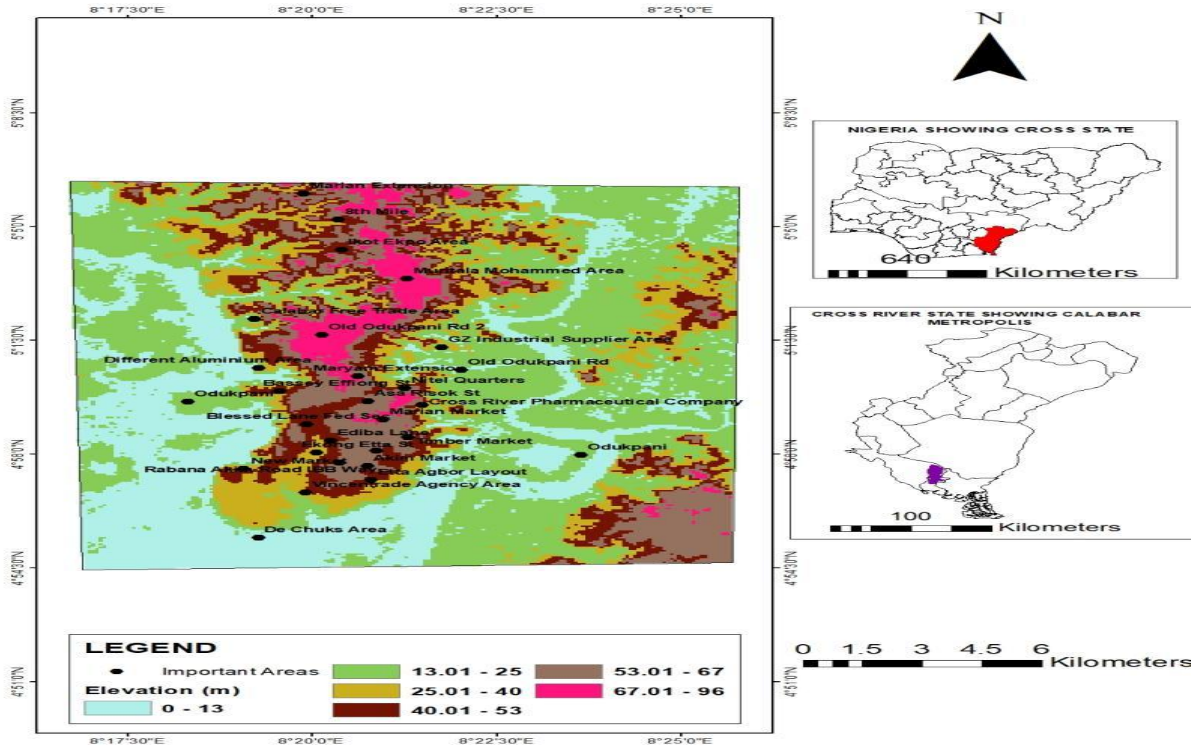

Figure 9: Elevation Classes of Calabar

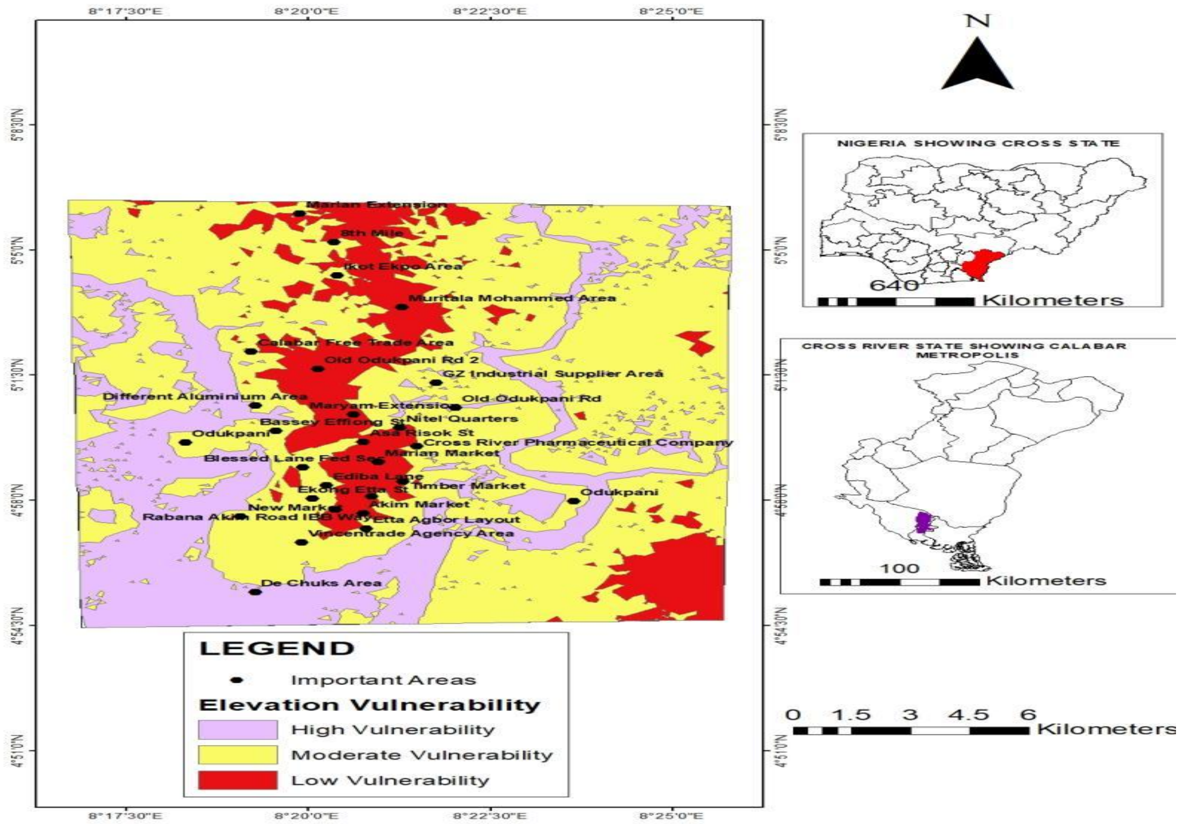

Figure 10: Elevation Vulnerability to Flood in Calabar

Table 4: Analysis of Elevation Levels and Vulnerability to Flood in Calabar

S/n	Elevation Level (m)	Spatial extent (sq km)	Percentage (%)	Vulnerability Assigned Values	Vulnerability Levels
1	0-13	91.13	25.44	3	High Vulnerability
2	14-25	129.96	36.28	2	Moderate Vulnerability
3	26-40	46.20	12.90	2	Moderate Vulnerability
4	41-53	39.47	11.02	2	Moderate Vulnerability
5	53-67	37.46	10.46	1	Low Vulnerability
6	67-96	14.03	3.92	1	Low Vulnerability
	Total	358.25	100.00		

Flood Vulnerability Levels and Developed Properties Vulnerability Levels in Calabar

The final flood vulnerability level in Calabar is displayed in Figure 11 and Table 5. It is shown that the low flood vulnerability in Calabar occupied a spatial extent of 115.04 sq km (32.04%), the moderately vulnerable area covered 162.13 sq km (45.16%) while the highly vulnerable area covered 81.86 sq km (22.80%). This shows that majority of Calabar Town are under moderately vulnerability to flood despite some areas are liable to have high flood vulnerability. The analysis displayed in Figure 12-14 revealed the location of developed properties under the low, moderate and high flood vulnerability levels in Calabar respectively while Table 6 reveals the number of developed properties categorized under the low, moderate and high flood vulnerability also. The analysis reveals that 121 developed properties were under the low flood vulnerability level and this amounted to 27.50% of the total number of developed properties captured. Similarly, 208 (47.27%) developed properties were found under the moderately flood vulnerability while 111 (25.23%) of developed properties were found under the highly flood vulnerability level.

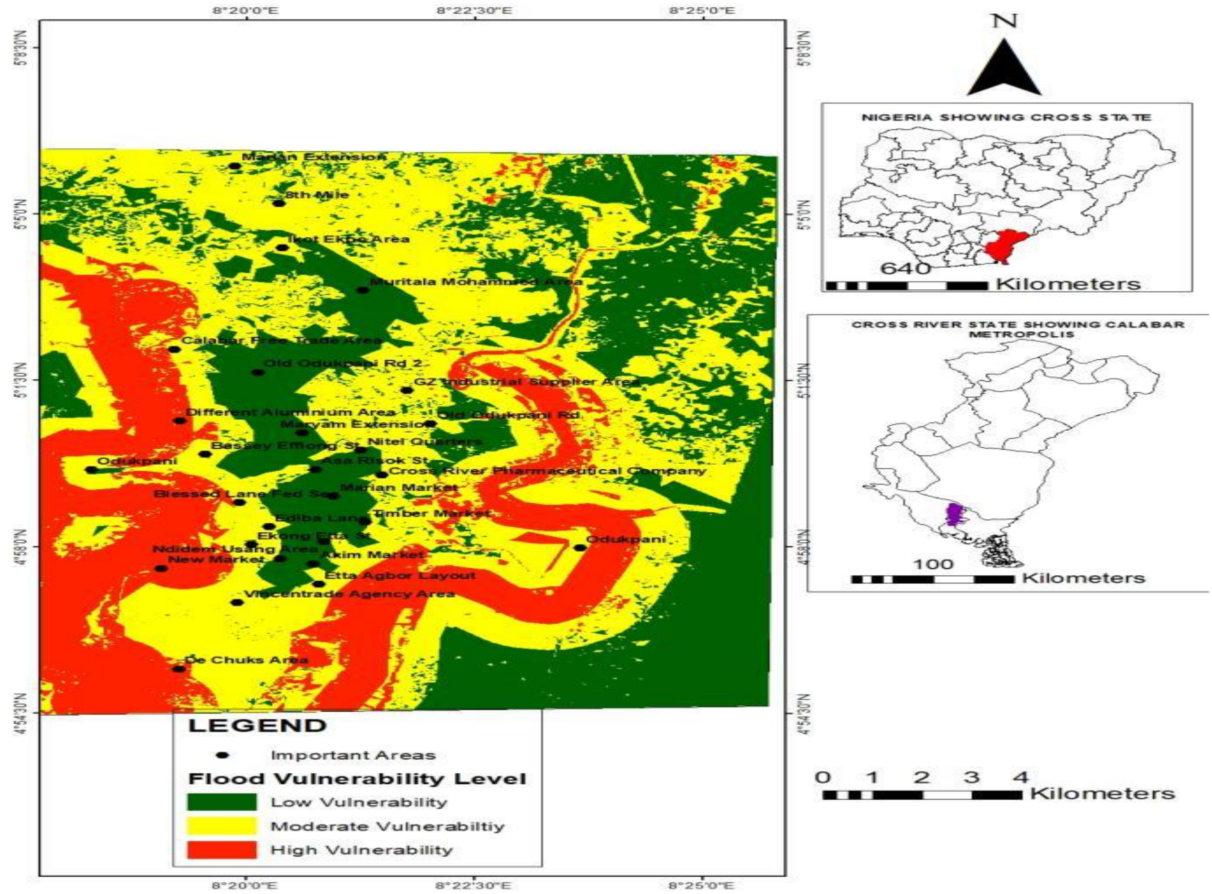

Figure 11: Flood Vulnerability Levels of Calabar Town

Table 5: Flood Vulnerability Levels in Calabar

SN	Vulnerability	Spatial Extent (km^2)	Percentage (%)
1	Low	115.04	32.04
2	Moderate	162.13	45.16
3	High	81.86	22.80
	Total	359.03	100.00

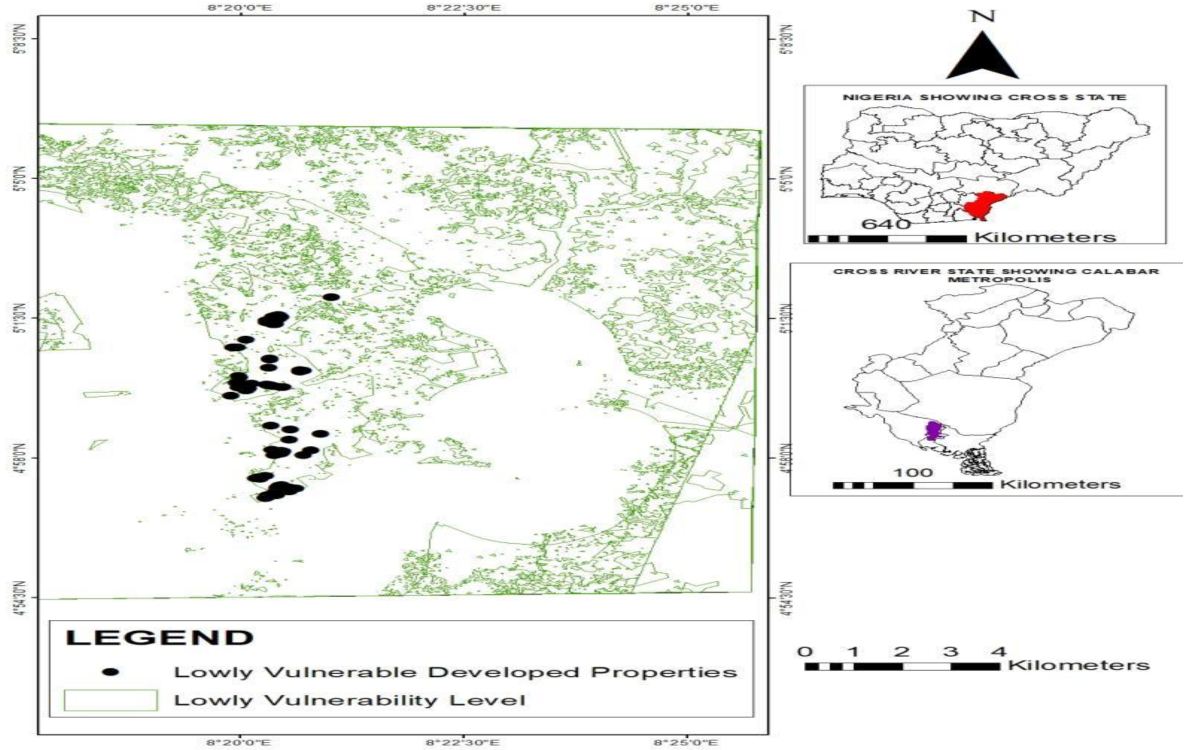

Figure 12: Developed Properties under Low Flood Vulnerability in Calabar

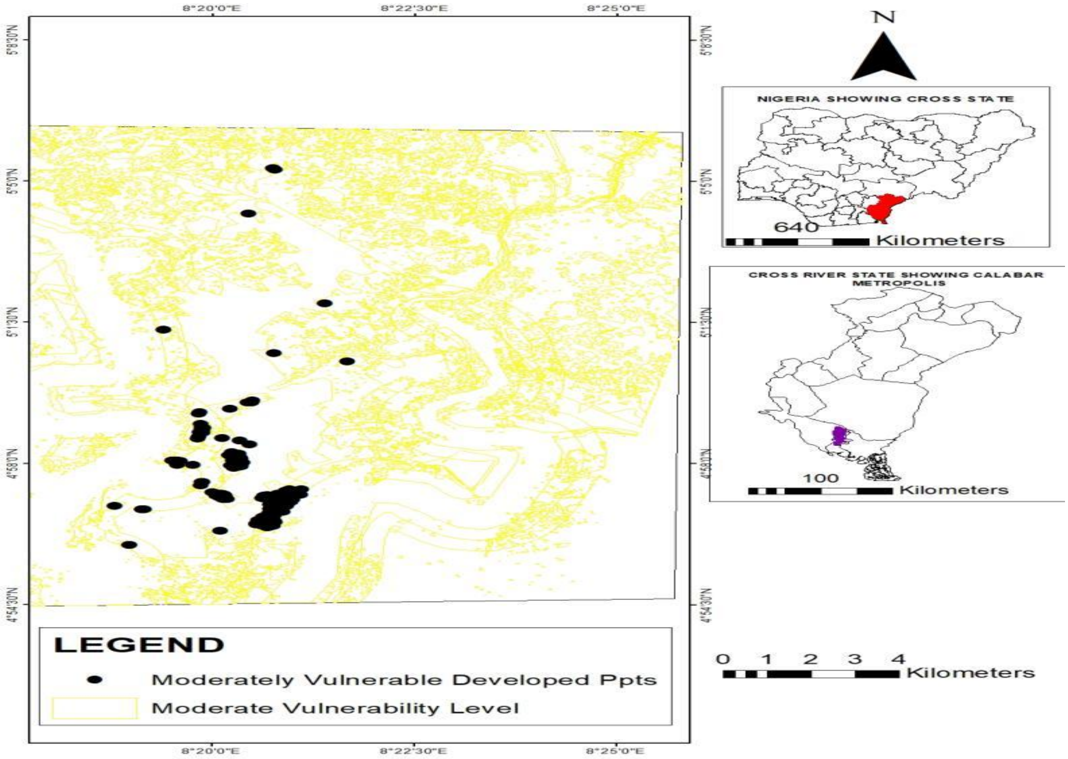

Figure 4.45: Developed Properties under Moderate Flood Vulnerability in Calabar

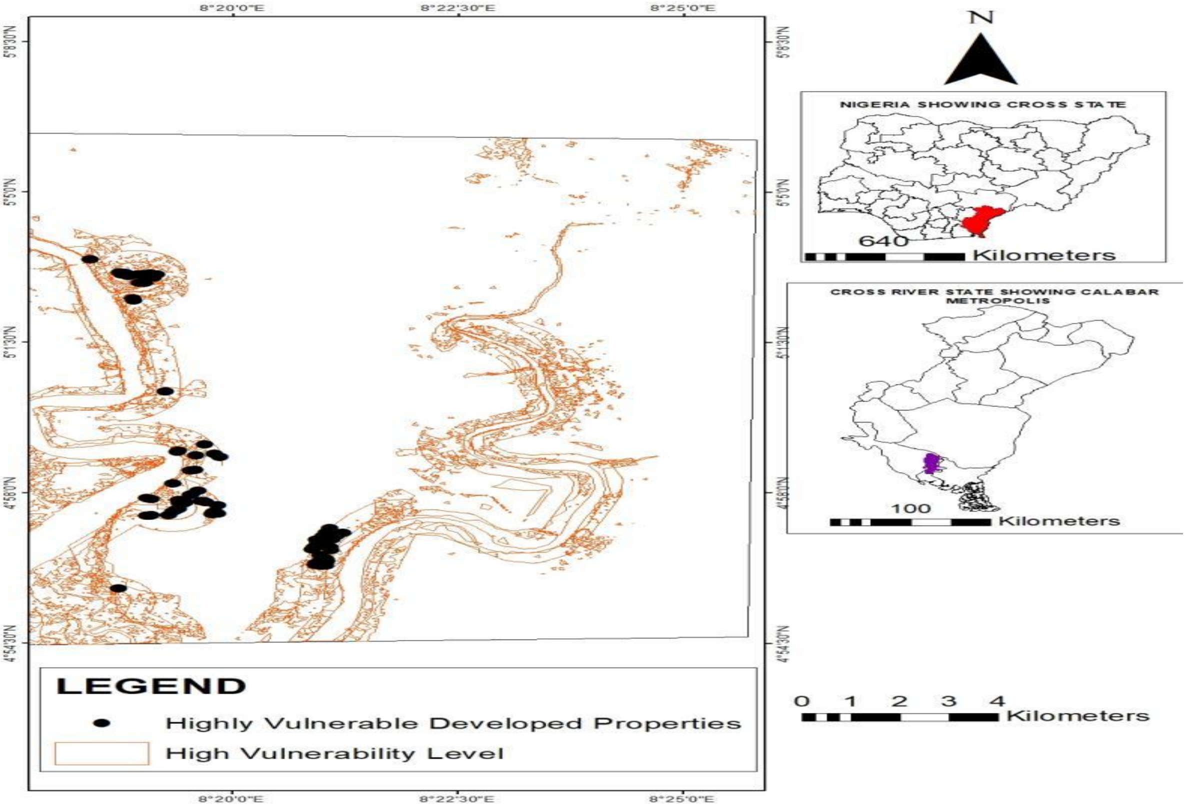

Figure 13: Developed Properties under High Flood Vulnerability in Calabar

Table 6: Developed Properties Vulnerability Levels to Flood in Calabar

SN	Vulnerability	Number of Developed Properties	Percentage (%)
1	Low	121	27.50
2	Moderate	208	47.27
3	High	111	25.23
	Total	440	100.00

IV. Conclusion

The Geospatial approach of the study further encourages the possibility of establishing the flood vulnerability level of developed properties in an environment. Using various physical environmental domains, there was a spatial distribution to the level of vulnerability among the developed properties in the Calabar metropolis. The study concluded that most of the developed properties in the metropolis have medium level of vulnerability. The study recommended the need for various engineering reinforcement to improved developed properties resilience to flood action.

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